PRODUCTION OF ETHANOL FROM BIOMASS ENGINEERING STUDY MATERIALS OF CONSTRUCTION OPTIONS FOR LARGE FERMENTATION VESSELS

SUBCONTRACT NO. TZ-2-12015-1

FOR

MIDWEST RESEARCH INSTITUTE AND
NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, CO 80401

BY

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FINAL

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SECTION 1.0
SCOPE OF STUDY

1.1 GENERAL

The Department of Energy, through the National Renewable Energy Laboratory has embarked upon a program to develop technologies for the production of fuel grade ethanol from renewable biomass resources. The major objective of this study is to evaluate technical and economic issues associated with the design of large, full scale fermentation systems required for the Biomass-to-Ethanol process.

The equipment to be considered in this study are the Fermentation Tanks and associated CIP (Clean-In-Place) equipment. Materials of construction and economies of scale are two major issues to be studied.

1.2 TASK DESCRIPTIONS

The work to be included in this study is described in Subcontract No. TZ-2-12015-1 under Task 1 and Task 2, as stated in the following Paragraphs.

1.2.1 Task 1 - Fermentation Tank Costs

Determine the purchased equipment costs and total installed costs for large fermentation tanks. The tanks are to be designed as atmospheric storage tanks. The normal operating temperature is 37°C. The materials of construction to be evaluated should include, but are not limited to the following:

- Carbon Steel
- 304 Stainless Steel
- 316 Stainless Steel
- Stainless Clad Carbon Steel
- Lined Carbon Steel

Total fermentation tank capacity is expected to be on the order of about 25 million gallons. Tank sizes to be considered include the following:

- 300,000 gallon working capacity
- 750,000 gallon working capacity
- Maximum size based on engineering judgement, economies of scale, and auxiliary requirements.

The following work shall also be performed with regard to Task 1:

- Determine the maximum tank size for the given conditions.
- Prepare a simple, preliminary tank specification for each tank size identified.
- Prepare preliminary data sheets for each tank size identified.
- Contact and discuss tank requirements with tank vendors, ultimately obtaining budgetary quotes from the vendors.

- Contact and discuss tank and lining requirements with lining/coating vendors, ultimately obtaining budgetary quotes and identifying viable alternatives from the vendors.
- Summarize technical information gained during investigation, including vendor data collected for incorporation into Final Report.
- Identify in the Final Report the associated subsystems or common design considerations not included in the estimate.
- Estimate Total Installed Costs using standard estimating practices.
- Prepare Purchased Equipment and Total Installed Cost Curves.
- Study the availability of present and future tank lining applications.

1.2.2 Task 2 - Clean-in-Place Equipment Costs

Periodically the vessels must be chemically cleaned to remedy or prevent microbial contamination. Systems are available for this service but the vessel size they can accommodate may be limited. Purchased equipment costs and total installed costs for clean in place systems are required. Materials of construction should be compatible with the conditions expected in the vessel, as well as with the cleaning solutions to be used.

The following work shall be performed with regard to the CIP System:

- Identify existing systems assuming the cleaning system to be a cleaning fluid followed by decontaminent, followed by a water flush. Steam cleaning will not be considered.
- Prepare simple, preliminary system specification for the CIP system(s) for each tank size identified.
- Prepare preliminary data sheets for the CIP system(s) for each tank size identified.
- Contact and discuss CIP requirements with vendors, ultimately obtaining budgetary quotes from the vendors.
- Summarize technical information gained during investigation, including vendor data collected for incorporation in the Final Report.
- Identify in the Final Report the associated subsystems or common design considerations not included in the estimate.
- Estimate Total Installed Costs using standard estimating practices.
- Prepare Purchased Equipment and Total Installed Cost Curves. Processing, treating and/or disposing of wastes from the CIP system(s) is not included in this Scope of Work.

1.3 DELIVERABLES

This formal, structured, technical report describes all significant work performed during the entire Subcontract. It includes Purchased Equipment Costs curves for the two systems described in Tasks 1 and 2. It also includes all information collected during the determination of the costs, including all vendor supplied literature, engineering information, and cost estimates.

SECTION 2.0
STUDY RESULTS

2.1 TASK 1

2.1.1 Determine the Maximum Tank Size for the Given Conditions

The total expected fermenting capacity of a full scale ethanol-from-biomass plant is stated to be 25 million gallons. It is possible to fabricate and erect a single cylindrical, flat bottom, supported cone roof tank with this capacity. The tank would be 300 feet in diameter and would have a 48 foot high shell. It can be shown that a single tank of these dimensions would also be the least expensive tank system to construct to achieve the 25 million gallon capacity. The maximum tank size to be considered for this facility therefore will not depend so much on tank design, fabrication and erection technology as it will depend on process requirements, and operating, maintenance and cleaning considerations.

On the basis of process and operating considerations it was decided that the maximum volume of the tank to be considered would be a tank of 1.5 million working gallons. A tank of this capacity, allowing additional volume for freeboard height above the operating liquid level, and allowing for a sloping bottom, would be 84 feet in diameter with a 40 foot high shell, at the highest point.

2.1.2 Prepare a Simple Preliminary Tank Specification for Each Tank Size Identified

Tanks with capacities as shown below are going to be considered in this study:

- 300,000 working gallons
- 750,000 working gallons
- 1,500,000 working gallons

Since all of these tanks are too large to be fabricated in a shop and shipped to the field in one piece, they would all have to be field erected. Industry standards that offer guidelines for the design, fabrication, field erection, inspection, and testing of such tanks are as follows:

- API-650, Welded Steel Tanks for Oil Storage
- API-620, Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks
- AWWA-D100, Standard for Welded Steel Tanks for Water Storage

A single, preliminary Project Specification for Field Erected Tanks, Specification B-1 was prepared based on the above industry standards, and is included in this report in Appendix A-1. This specification is applicable to any size tank, but assumes the tank configuration to be vertical, cylindrical, with a sloping flat bottom, and a self supporting dome or umbrella roof. The specification is written to apply to unlined tanks of carbon steel construction, with supplements to specify requirements for other materials of construction and other items of equipment as follows:

- Supplement A - Painting and Coating

- Supplement B - Clad Construction
- Supplement C - Stainless Steel Construction
- Supplement D - C.I.P. System

2.1.3 Prepare Preliminary Data Sheets for Each Tank Size Identified

Preliminary Tank Data Sheets/Control Drawings have been prepared, and are included in this report as Appendix A-2. Tank Data Sheets/Control Drawings included are:

- Drawing T-100 for a tank of 300,000 working gallons, 322,400 total gallons. This tank is 42 feet in diameter with a 32 foot high shell, flat sloping bottom, and a self supporting dome or umbrella roof.

- Drawing T-200 for a tank of 750,000 working gallons, 820,000 total gallons. This tank is 60 feet in diameter with a 40 foot high shell, flat sloping bottom, and a self supporting dome or umbrella roof.

- Drawing T-300 for a tank of 1,500,000 working gallons, 1,590,000 total gallons. This tank is 84 feet in diameter with a 40 foot high shell, flat sloping bottom, and a self supporting dome or umbrella roof.

2.1.4 Contact and Discuss Tank Requirements with Tank Vendors, Ultimately Obtaining Budgetary Quotes from Vendors

The tank sizes and configurations considered for this report are not unusually large or complicated and could be fabricated and erected quite readily by any number of tank fabricators/erectors nationwide. There are methods available for estimating the costs of field erected tanks based on historical data of equipment purchased for use by industries and municipalities, and on estimating data furnished to publishers of equipment estimating guides by tank fabricators and erectors. These "in-house" methods of estimating equipment costs eliminate having to prepare a bid package and distribute it to a number of vendors, wait to obtain "Budget Estimates", and then evaluate the vendor responses to determine which quoted budget price to use. It is our experience that if three vendors are asked to bid budget tank erection costs, that the price difference between the high and low bid could be as much as 100%, or even more.

It was decided to use "in-house" methods for estimating the costs of these tanks, and then discuss the tank materials and configurations with various vendors to identify problem areas.

Information used for producing the "in-house" estimates was taken from:

- <u>"Estimate Costs of Heat Exchangers and Storage Tanks via Correlations"</u>, January 25, 1982, Chemical Engineering Magazine

- "Richardson Engineering Services, Inc. Process Plant Construction Estimating Standards 1992 Edition, Volume 4, Storage Tanks, Section 100".

Estimate information, calculations, references, etc. are included in Appendix A-3.

Fabricators and erectors of field erected tanks who were contacted with regard to these tanks are as follows:

- Wyatt Field Services Co.,
  P.O. Box 3052
  Houston, TX 77253
  Ph: 713-861-6141
  Division of Nooter Corp.

- Kennedy Tank and Manufacturing Co, Inc.
  833 E. Sumner Ave., Box 27070
  Indianapolis, IN 46227
  Ph: 317-787-1311

- CB&I Services, Inc.
  41777 Boyce Road, Box 5005
  Fremont, CA 94537-5005
  Ph: 510-657-1600

- Pittsburgh-Des Moines, Inc.
  Neville Island
  Pittsburgh, PA 15225
  Ph: 412-331-3000
  Houston Office Ph: 713-875-6840

- Eaton Metal Products
  4800 York St.
  Denver, CO 80216
  Ph: 303-296-4800

- Brown-Minneapolis Tank
  P.O. Box 43670
  St. Paul, MN 55164
  Ph: 612-454-6750

Steel manufacturers contacted, to check the price of T316L Stainless Steel vs T316L Clad Carbon Steel were as follows:

- Lukens Steel Co.
  50 So. First Avenue
  Coatesville, PA 19320
  Ph: 1-800-441-8344 or 215-383-2616

- Jessop Steel Co.
  4201 FM 1960 West
  Suite 221
  Houston, TX 77068
  Ph: 713-537-8577 or 2585

Material quotations from these manufacturers are included in Appendix A-3. These quotations verified comments received from tank fabricators and erectors, with regard to material costs for stainless steel and stainless steel clad carbon steel.

Based on discussions with the tank fabricators and erectors listed above, and past experience, the following comments are made with regard to the design, fabrication, and erection of the tanks:

1. None of the tank fabricators/erectors contacted had ever built a field erected tank of stainless steel clad carbon steel. Their experience has shown that in the range of plate thicknesses required for these tanks, thicknesses of 3/16" to 1/2", that clad steel tanks will cost more than solid stainless steel tanks. The thickness at which to consider using clad steel construction is in the range of 1" to 1 1/4" plate and above. The reasons for this are:

    - Solid stainless steel plates are no more expensive, and in some cases are less expensive than 1/8" thick stainless steel clad on 3/16" thick to 1/2" thick carbon steel backing plates, as verified by quotes received from steel manufacturers.

    - Fabrication procedures for clad steel construction are much more complicated and expensive than for solid carbon steel or stainless steel fabrication.

    - Inspection and testing procedures for clad steel construction are more complicated and expensive due to having to test all the weld overlay chemistry.

2. For a large project such as this, the construction schedule could be affected due to a lack of welders and erectors skilled in the fabrication and handling of clad plate. The fabrication of solid stainless steel requires less skill and less time.

3. If the tank interior surface must be stainless steel, either solid or clad to a carbon steel backing plate, the required finish condition of the plate and weld joint surfaces should be considered and specified. If all welds are required to be ground flush with the surrounding base material to facilitate cleaning operations, or if the welds must be ground and polished to match the finish of the surrounding plate surfaces which have also been bought in a polished condition, labor costs will be increased considerably. See Appendix A-5 for a description of available finishes, and associated costs.

4. If mixing of the contents and cleaning of the interior surfaces are going to be considerations, then a self supported roof with no internal stiffeners will probably be required. This will eliminate all internal roof support columns and support beams to facilitate mixing and cleaning, but the maximum diameter of the tank will then be limited by the design of the roof, and an 84 foot diameter unsupported dome or umbrella roof is probably approaching the design and fabrication limits for many manufacturers, however, self supporting umbrella roofs in sizes to 200 feet in diameter have been built. The roof could be stiffened as long as all the stiffeners were located on the outside surfaces. The dome or umbrella roof should be specified to be butt-welded to the top edge of the shell to form a smooth transition between the roof and shell that can be cleaned.

5. Fiberglass and aluminum domes are available from many manufacturers to serve as tank roofs for many applications, however, they cannot be attached to the top of the cylindrical

tank wall without a ledge or lip support that would be impossible to clean, therefore these types of roofs are not going to be considered.

6. If the slope of the tank bottom has to be increased to any great extent, or the design made more complicated to facilitate drainage of settled solids to a single outlet at the junction of the shell and bottom, the cost of the tank would be effected due to the more complicated design required for the foundation and bottom plates.

7. Consider other configurations for the tanks, such as spherical and oval shapes which are used for digesters. See Appendix A-6.

   These "alternate" configurations will not be less expensive, but might be more suitable from a process and cleaning capability standpoint.

2.1.5 Contact and Discuss Tank and Lining Requirements With Lining/Coating Vendors, Ultimately Obtaining Budgetary Quotes and Identifying Viable Alternatives from the Vendors

In order to be able to obtain manufacturer's recommendations for tank lining/coating materials that would be suitable for our conditions, it was necessary to develop a preliminary conditions-of-service specification fully describing the process conditions that the lining/coating material will be exposed to. This preliminary "Conditions-of-Service for Fermentation Tank Lining/Coating Recommendation" is included in Appendix A-4, and was sent to a number of manufacturers of tank lining/coating materials, for their recommendation of a lining/coating system, and a budget estimate of material and application costs for the systems recommended.

Each lining/coating manufacturer specializes in particular formulations of materials to perform satisfactorily under different conditions of service. Some manufacturers have a very broad and varied line of products from which to make a recommendation, and some have a very limited and specific line of products that are applicable to very specialized industries or applications.

The manufacturers contacted were chosen so that recommendations made would be for as many different lining/coating formulations as possible. Manufacturers responding to our inquiries, and their material recommendations and estimated cost are as follows. Vendor catalog specification sheets for all coatings recommended are included in Appendix A-4:

1. Devoe Coatings
   Louisville, KY
   Phone: 1-800-826-0252
   Local Denver, CO Representative 303-324-7958

   Product Recommendation - DEVCHEM #253
   Product Description - Advanced Technology Epoxy
   Application - (2) coats at (6) mils each
   Material Cost - $1.00 per ft^2 (incl. freight, Subcontractor markup, and 20% loss)
   Application Cost - $1.50 per ft^2
   Total Applied Cost - $2.50 per ft^2

NOTE: The manufacturer would not quote estimated application costs. He recommended obtaining application costs from a coating applications contractor. Applied costs were estimated "in-house" from available cost data for application of (2) component, (2) coat epoxy systems.

2. Dudick, Inc.
Streetsboro, OH
Phone: 216-562-1970
Local Denver, CO Representative 303-455-5790

Product Recommendation - PROTECTO-COAT #605
Product Description - Graphite Flake Filled Polyester-Based Resin
Application - (2) coats at (15-20) mils each
Material Cost - \$2.00 to \$2.25 per ft^2
Application Cost - \$3.00 to \$4.00 per ft^2
Total Applied Cost - \$5.00 to \$6.25 per ft^2

NOTE: The manufacturer would not quote estimated application costs. He recommended obtaining application costs from a coating applications contractor. A later telecon indicated application costs as stated above.

3. Elf-Atochem (Formerly Pennwalt)
Corrosion Resistant Linings
Local Denver, CO Representative - Interep, Inc. 303-277-0401

Product Recommendation - PENNCOAT MEMBRANE SYSTEM #401
Product Description - Silicone-Based Polymeric Lining
Application - (2) coats at (15-20) mils each
Total Applied Cost - \$5.10 to \$6.45 per ft^2

NOTE: The manufacturer did not quote separate material and application costs.

4. Wisconsin Protective Coatings
Green Bay, WI
Phone: 414-437-6561

Product Recommendation - PLASITE #9570
Product Description - Low temperature bake (250°F), modified epoxy with amine curing agent
Application - (2) coats at (6-8) mils each
Material Cost - \$0.60 per ft^2
Total Applied Cost - \$5.00 to \$8.00 per ft^2
Includes Bake Cost - Bake at 250°F for 2 hours;

Note: Steel temperature must be at 250°F.

Comments:

The application of this product would not be practical for a tank of this size. The exterior surfaces of the tank would have to be insulated and the interior would have to be heated to bring the steel temperature to 250°F and maintain the steel at that temperature for (2) hours.

The manufacturer would not quote estimated application costs. He recommended obtaining application costs from a coating applications contractor. Estimated total applied cost was obtained verbally from another manufacturer, for a similar product.

5. Inorganic Coatings, Inc.
   Malvern, PA
   Phone: 800-345-0531

   Cannot recommend one of their products for our application. They specialize in coatings for exterior surfaces and recommend their IC-531 inorganic zinc silicate product for painting the exterior surfaces of these tanks.

6. Electro-Chemical
   Engineering and Manufacturing Co.
   Emmaus, PA
   Phone: 215-965-9061

   Product Recommendation #1 - EL CHEM Duro-Bond PVDF
   Product Description - .050" PVDF on .050" Rubber Backing, Sheeting
   Total Applied Cost - $70.00 to $75.00 per ft^2

   Product Recommendation #2 - EL CHEM Duro-Bond PVDF
   Product Description - .060" PVDF on .060" Rubber Backing, Sheeting
   Total Applied Cost - $55.00 to $60.00 per ft^2

- All of the lining/coating manufacturers recommend obtaining application costs for their materials from coating application contractors. Application costs can vary widely depending on the size of the total painting/coating project and on the contractors experience in applying the recommended coating. Some manufacturers maintain a list of recommended contractors with experience in the application of their specific products. For this study, due to time constraints and the variety of coatings/linings under consideration, we did not obtain quotations from application contractors.

- It was recommended that for our conditions of service, with the range and combinations of chemicals involved in the fermentation process and cleaning procedures, and the biological considerations which are presently an unknown, that a testing program be initiated for lining/coating systems being considered to assure satisfactory performance. Test solutions would be furnished to manufacturers who would develop test cells for each coating and chemical solution, and perform immersion tests over a long period of time (90 day minimum) to verify suitability of lining materials with regard to chemical and <u>biological attack</u>, blistering, pinholes, bonding, etc. Some manufacturers will qualify their recommendation for a coating/lining material based on such a testing program.

- Elf-Atochem (formerly Pennwalt) stated they are presently doing development work on thin film linings with increased chemical resistance, and that as they are developed, it may be advisable to consider them from a cost standpoint.

- Most coating/lining manufacturers presently have development programs for new products under way, and it is recommended that as this full scale production plant comes closer to becoming a reality that test programs be initiated with several manufacturers which might prompt development of a lining for this specific application.

2.1.6 Summarize Technical Information Gained During Investigations, Including Vendor Data Collected for Incorporation Into this Final Report.

2.1.6.1 Technical information with regard to materials of construction

- Carbon Steel

  - Acidic solutions (pH less than 5) are highly corrosive to carbon steel, except for some oxidizing acids. Corrosion rates at 40°C for pH = 5 to 10 is in the range of 18-20 mils per year. Below a pH of 5, especially with CO_2 present, the corrosion rate increases dramatically. With CO_2 present, some recommend not going below a pH of 6.

  - Sodium hydroxide can cause caustic embrittlement, or stress-corrosion cracking of carbon steel materials depending on concentration and temperature conditions. A 3 to 5% solution should remain below 200°F, a 20% solution below 150°F. Most problems with stress corrosion cracking of carbon steels occurs in the welds, because of residual stresses. Stress relieving of welded structures which are not otherwise highly stressed in service, can usually eliminate stress corrosion cracking problems, but is not a practical consideration in tanks of this size.

- Austenitic Stainless Steels (T304 and T316)

  - Corrosion from organic compounds is not a problem with the T304 and T316 grades of austenitic stainless steels, except in a few specific cases not normally encountered. The Type 316 austenitic grade is more resistant than the Type 304 grade, particularly if any salts are present.

  - Carbonic acid has no effect on the stainless steels, and is used extensively in carbonating equipment, therefore the CO_2 in solution will not affect the stainless steels, except,

  - When subjected to the temperature range of 800°F to 1650°F, the austenitic stainless steels undergo a change in structure that renders them susceptible to intergranular corrosion upon exposure to a number of acids, including organic acids, that would normally have no effect on the material. Holding the carbon content to a maximum of .03% as in the T304L and T316L grades is sufficient to avoid sensitization during welding, and therefore T316L is recommended for use in this equipment, if an austenitic grade of stainless steel is going to be used.

- The most severe problem with the use of the austenitic stainless steels for this application would be if biomass or other debris, marine growths, or biological sludges settle or accumulate on the surface of the steel, cutting off the oxygen supply. This can lead to serious pitting and crevice corrosion problems because the passive layer which acts to prevent corrosion in these steels is dependent on a supply of oxygen to maintain the protective passive film. If good aeration and mixing with moderate velocities and turbulence are maintained, this will not be a problem. The T316 grade of austenitic stainless steel contains 2 to 3 percent molybdenum which makes it more resistant to pitting corrosion. See Appendix A-9 for articles which discuss this in more detail.

2.1.6.2 With Regard to Vendor Data

- All vendor data received is contained in the Appendix of this report.

2.1.7 Identify in This Final Report the Associated Subsystems or Common Design Considerations Not Included in the Estimate

2.1.7.1 Exterior Painting

Exterior painting of all carbon steel or stainless clad carbon steel tanks would be required. Exterior painting systems are dependent upon exterior surface exposure conditions (i.e. chemical splash, spill, or fumes; industrial atmosphere; sea coast, marine atmosphere; etc.) which would be determined when the plant location is decided upon. Exterior paint systems application could be included in the internal tank lining/coating subcontract so that one contractor would have total responsibility for all phases of paint, coating and lining applications.

A cost estimate is included for painting exterior carbon steel surfaces; however, this cost can vary over a wide range depending upon exposure conditions. Painting costs included in the estimate are for "severe exposure" conditions.

2.1.7.2 Foundation Systems

This estimate does not include the cost of foundation systems for the tanks. The foundation system required will be the same for tanks of equal size regardless of the tank material, but the cost of the foundation on a dollar per gallon basis will decrease as the tank size increases. Foundation design and costs will be very "site specific" depending upon site terrain and geologic factors. The final configuration of the tank bottom will also affect the cost of the foundation (See 2.1.4.6).

2.1.7.3 Cathodic/Anodic Protection Systems

This study has not considered the subject of cathodic/anodic protection for the carbon steel tanks. Areas to be concerned with include the outside surface of the bottom of the tanks if it rests on the ground, and the inside surfaces of the lined/coated tanks to protect the carbon steel at imperfections in the coating, such as at pinholes which might expose a small area of the carbon steel plate. If the inside surface of the tank is not coated, the entire surface acts as an anode and corrosion occurs slowly at a relatively steady rate over a long period of time. However, if the inside surface is coated, only those small areas of metal exposed by pinholes and other imperfections are anodic, and will corrode very quickly due to the small area exposed. This can result in pinhole leaks at these areas.

Some firms which specialize in the design and installation of cathodic/anodic protection systems, which could be consulted with regard to this subject, are as follows:

- Norton Corrosion Limited
  22327 - 89th Ave. S.E., Dept. T
  Woodinville, WA 98072
  Ph: 206-483-1616

- PCA Engineering, Inc.
  177-T Royal Ave., P.O. Box 227-T
  Hawthorne, NJ 07507-9227
  Ph: 1-800-666-PCA1

2.1.7.4 Inside Surface Finish Requirements

This estimate is for the cost of erecting a storage or process tank of industrial quality, with no special provisions to control the finish and imperfections of the inside surfaces. If the biological state of cleanliness required after cleaning is going to require that uncoated carbon or stainless steel surfaces be finished to better than commercial quality, or that all the welds on the inside surface be ground flush, or polished, then this will add to the cost of the tank.

The finished surfaces of most spray applied coatings and linings are very smooth, with few imperfections. The coating material has a tendency to fill the gouges, scratches and surface imperfections in the plates due to rolling, fabrication procedures and handling. Usually, the thicker the coating, the smoother the finished surface will be. Most linings also have a good surface finish; however, any lining material would have to be seamed, and the seams might present problems when cleaning operations are considered.

2.1.7.5 Corrosion Test Programs for Metals. Chemical Compatibility Test Programs for Coatings/Linings.

Prior to making a final decision with regard to materials of construction for the tanks, a program of corrosion testing, using corrosion test coupons should be initiated to determine corrosion rates and other effects of all process and cleaning solutions that the materials under consideration will be exposed to. Test coupons should include welds.

A similar test program should be initiated to determine suitability of various lining materials. Test programs for lining materials can be arranged with lining manufacturers. (See Para. 2.1.5).

2.1.7.6 Design of the Tank Bottom

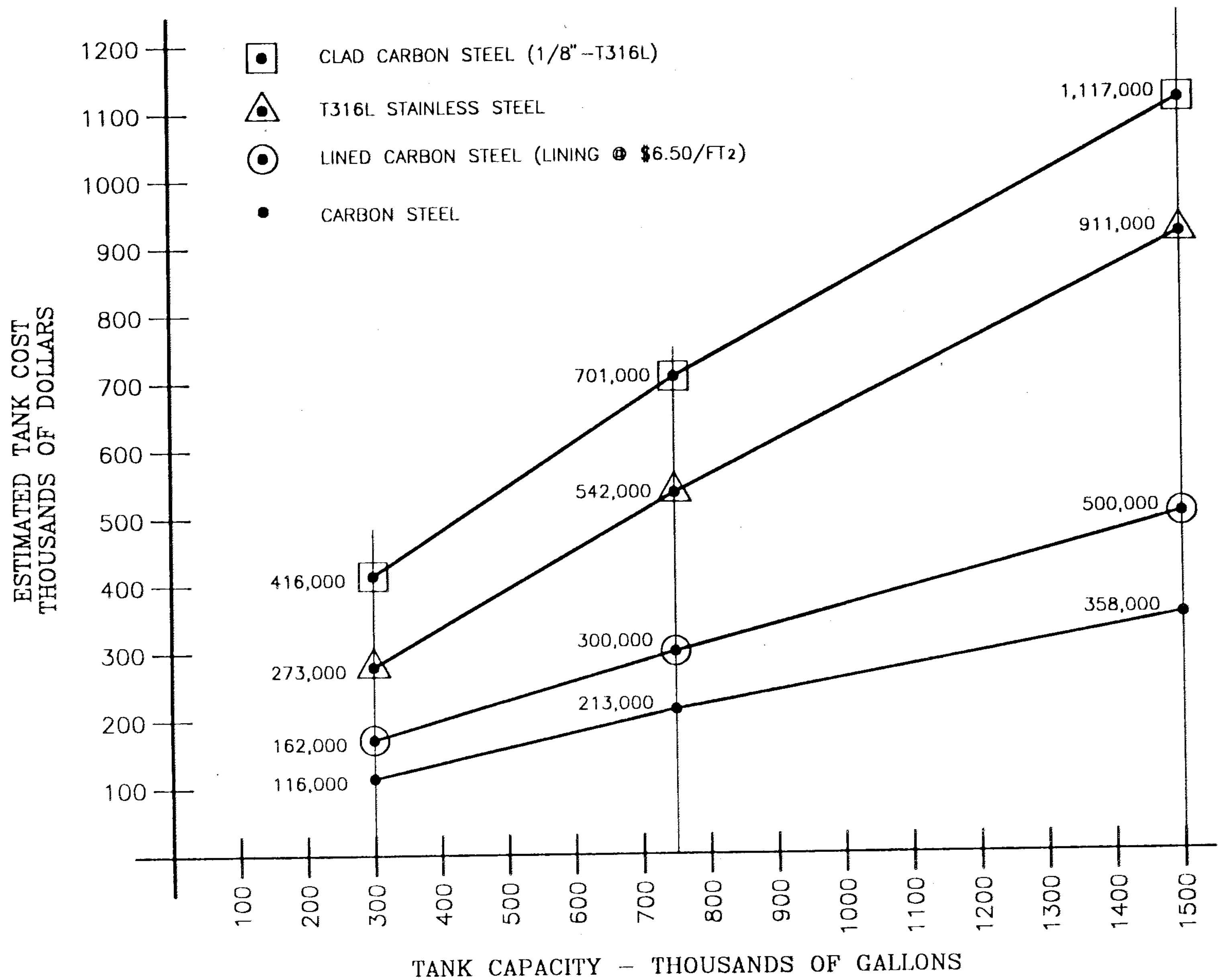
If design of the tank bottom, when finalized, results in any configuration other than a simple sloped bottom due to cleaning considerations, then this will add to the cost of the tank and its foundation; for example, a supported cone bottom with center drain, or a more steeply sloped, or dual-sloped bottom, would be more complicated and expensive. Some articles which discuss the items to consider in deciding what type of bottom to specify are included in Appendix A-7.

2.1.8 Estimate Total Installed Costs Using Standard Estimating Practices.

Cost estimates for carbon steel tanks were made using two different methods, as stated below. Results of the two methods were then averaged, and the average was used as the basic tank cost. The cost for tanks fabricated of other materials were then factored using the cost of the carbon steel tank as a basis. Additional costs for exterior painting of carbon steel and clad carbon steel tanks, for lining the interior of carbon steel tanks, and for providing access stairways, walkways, and platforms to all tanks were then added, and the final figures were plotted as shown in Figure 1. Estimate worksheets and reference material is included in Appendix A-5.

- Method 1- "Estimate Costs of Heat Exchangers and Storage Tanks via Correlations," January 25, 1982.

- Method 2 - "Process Plant Construction Estimating Standards - Volume 4," Richardson Engineering Services, Inc., 1992 Edition.



NOTE:
COSTS ARE FOR A COMPLETE TANK ON FOUNDATIONS FURNISHED BY OTHERS. COST INCLUDES EXTERNAL STAIRWAY AND ROOF PLATFORMS/WALKWAYS AND EXTERIOR PAINT.

TANK CAPACITY/MATERIAL (VS) COST
FIGURE 1

United Engineers & Constructors A Raytheon Company Stearns-Roger Division		
SHT. NO.	JOB NO. 6299.001	REV.

2.1.9 Study the Availability of Present and Future Tank Lining Applications.

The broad range of materials available as suitable lining/coating systems for these tanks, and the equally broad range of quoted applied costs, from $2.50 to $75.00 per sq. ft., makes this a difficult subject to assess. Subject to testing the recommended materials prior to actual use, it appears it will not be a problem to locate a lining/coating system suitable for these tanks and this process. In the future there may be even more system/material options available, which will make the task of recommending a single coating system even more difficult.

2.2 TASK 2

2.2.1 Identify Existing Systems Assuming the Cleaning System to be a Cleaning Fluid Followed by a Decontaminent, Followed by a Water Flush. Steam Cleaning Will Not be Considered.

2.2.1.1 Existing tank cleaning equipment, for tanks of this size, consist of hydraulic or air driven rotary cleaning machines, or heads. These heads deliver high velocity jets of water from nozzles which revolve in a vertical plane. This vertically revolving head is assembled to a body that revolves in a horizontal plane. The combination of vertical and horizontal rotation results in a 360° spherical cleaning pattern. In many cases the jet nozzles are removable so that flow rates and impact velocities can be changed without changing the entire head. In many cases it is possible to adjust both the vertical and horizontal rotational speeds to change the length of time of the cleaning cycle.

2.2.1.2 The cleaning machine, or head, is usually mounted to a fixed lance attached thru a blind flange on a nozzle located at or near the center of the tank. The fixed lance length is set to strategically locate the cleaning head at a position in the tank that will allow the cleaning solutions to impact and flush all surfaces of the tank walls and internals. In some cases, where the tank is very large in diameter, or very high, or if internal baffles or equipment shield areas from impingement of the cleaning solutions, more than one machine per tank or more than one type of machine may be required.

2.2.1.3 Telescoping and tilting lances are also available so that the position of the cleaning head inside the tank can be adjusted. This adjustment can be done manually, or the process can be fully automated, via computer aided robotic systems.

2.2.1.4 Cleaning systems can be designed to operate with pressures over 20,000 psig. Most systems are designed for pressures in the 100-200 psig range, and with liquid flow rates of 100 to 200 GPM.

2.2.2 Prepare a Simple, Preliminary System Specification For The CIP System For Each Tank Size Identified

A single CIP system specification is included as SUPPLEMENT D in the PROJECT SPECIFICATION FOR FIELD ERECTED TANKS FOR ETHANOL PRODUCTION VIA ANAEROBIC DIGESTION/FERMENTATION PROCESS, SPEC. B-1. This Specification can be used for any of the tank sizes and configurations presently under consideration. This specification should be expanded as the system to be used for these tanks become more well defined. This Specification is included in APPENDIX A-1.

2.2.3 Prepare Preliminary Data Sheets for the CIP System(s) for Each Tank Size Identified

In order to be able to prepare Equipment Data Sheets for the CIP equipment items, the cleaning conditions and the cleaning procedures must be more well defined. The vendors of the equipment must be given information with regard to:

- Material, or composition of the surfaces to be cleaned
- Cleanliness levels required for each cycle
- Shielded, or unaccessible areas requiring cleaning
- Frequency of cleaning
- Detailed description of all materials to be removed from tank surfaces, i.e. hard/crusted, soft/soluble, bacteriological sludge, sticky/tenacious, organic/inorganic, sediment, foam, etc.
- Cleaning solution supply pressure limitations
- Tank configuration and size. Furnish tank data sheets to the vendors

At this point, not enough detailed information with regard to the above items is available to be able to develop even a preliminary equipment data sheet. In addition, we are still in the process of receiving vendor data and information with regard to systems and equipment available, and require more vendor data in order to be able to develop a detailed data sheet.

2.2.4 Contact And Discuss CIP Requirements With Vendors, Ultimately Obtaining Budgetary Quotes From The Vendors

Information received from Vendors with regard to CIP equipment and systems available is included in Appendix A-10.

Manufacturers and vendors of CIP equipment contacted are as follows:

- Toftejorg, Inc.
  2614 East Beltway Eight
  Pasadena, Texas 77503

  Phone: 713-487-7851

Toftejorg does not furnish entire CIP systems, only the cleaning machines or heads that mount in the tank. They quoted their cleaning head model #TZ-75 at $2,472.85 + $464.99 for their stainless steel installation assembly. This unit would be applicable for all of the tank sizes being considered. They also quoted their cleaning head model #TZ-67 at $2,727.95, and a pneumatically operated industrial retracta-system at $47,079.51.

- Sybron Chemicals, Inc.
  Gamajet Equipment Div.
  21066 Alexander Ct.
  Hayward, California 94545

  Phone: 1-800-356-7807

Gamajet did not quote prices for our particular application, but did send descriptive literature of their cleaning machines, or heads, and their automated telescoping system. They furnish just the cleaning machines or heads, not entire systems.

- Spraying Systems Co.
  North Ave. and Schmale Road
  Wheaton, Illinois 60188

  Represented by: Al Buhl & Associates
  1600 Broadway, #2035
  Denver, Colorado 80202

  Phone: 303-830-9002

Spraying Systems Co. does not furnish entire CIP Systems, only the machines or heads that mount in the tank. They quoted their cleaning head Model #290A at $3697.80 in quantities of (20) or more. This unit would be applicable for all of the tank sizes being considered.

- Chemdet, Inc.
  50 Sintsink Drive East
  Port Washington, NY 11050

  Phone: 516-883-1510

Chemdet does not furnish entire CIP Systems, only the machines or heads that mount in the tank. They quoted their Fury Model #600 with a 12 mm nozzle at $3150. This unit would be applicable for all the tank sizes being considered.

- NLB Corporation
  201 So. 16th St.
  LaPorte, Texas 77571

  Phone: 713-471-7761

NLB Corporation did not quote a specific cleaning machine or system for our application, but forwarded information explaining their capabilities and experience in CIP component and system design.

- Automated Hydro-Systems, Inc.
  27930 Groesbeck
  Roseville, Michigan 48066

  Phone: 313-772-9696

Automated Hydro Systems, Inc. did not quote a specific cleaning machine or system for our application, but forwarded information explaining their capabilities and experience in CIP component and system design.

- Butterworth Tank Cleaning Machines, Inc.
  16737 W. Hardy St.
  Houston, Texas 77060

  Phone: 713-821-7300

Butterworth does not furnish entire CIP systems, only the machines or heads that mount in the tank. They quoted their Type LT machine for our application, at $2,495 each. This unit would be applicable for all the tank sizes being considered.

Other manufacturer contacted for information who did not respond at this time, but should probably be considered for future work are:

- Advance Water Blast Systems, Inc.
  186 Rio Circle
  Decatur, Georgia 30030

  Phone: 404-373-0137

- Niagara National Corp.
  2160-C Hills Ave. Dept. A
  Atlanta, Georgia 30318

  Phone: 1-800-635-8342

- T.C.M. Corp.
  3075 Richmond Terrace, Box 118
  Staten Island, New York 10303

  Phone: 718-442-8190

A supplier of sanitization chemicals responded to our inquiry as follows:

- Alltech Biotechnology Center
  3031 Catnip Hill Pike
  Nicholasville, Kentucky 40356
  Phone: 606-885-9613

2.2.5 Summarize Technical Information Gained During the Investigation, Including Vendor Data Collected for Incorporation into the Final Report.

2.2.5.1 For the range of tank diameters under consideration (42 ft. dia. to 84 ft. dia.), it does not appear that there will be any problem in locating tank cleaning machines, or heads able to deliver the cleaning solutions to the inside surfaces for scrubbing, flushing, and disinfection. The problem will be to determine what force or velocity will be required at the walls and roof to loosen sludge, scum, and soil or scale deposits, and what flow rate will be required to flush the solids from the tank. Another problem will be to assure that all settled solids located on the floor of the tank can be loosened and flushed out.

2.2.5.2 The ability to remove solids from the tank will depend upon the design of the sloping floor of the tank, and the liquid flow rate required to flush solids dislodged from the roof, walls, and floor all the way across the bottom of the tank to a low point drain outlet, or to a center drain outlet. The liquid velocity across the floor of the tank will have to be sufficient to entrain solids and maintain them in suspension to the outlet. Slopes of 1" to 2" per foot are recommended for digesters where sludge is withdrawn from the center of the tank. See Appendix A-7.

2.2.5.3 Provision should be made to assure the outlet will not pack with settled solids during the fermentation process, and thus be plugged when it becomes time to drain the tank.

2.2.5.4 The internal surfaces of the tank should be as smooth and free of attachments, nozzle openings, penetrations, baffles, cooling coils, mixers, etc. as possible. Every internal will shield an area of the wall from the cleaning spray, and require that either multiple cleaning heads be installed, or that cleaning heads be mounted on telescoping, articulated lances to change the head position so that all surfaces can be impacted. These devices are very expensive (by a factor of 10 to 20) when compared to the cost of a cleaning head mounted to a fixed lance.

2.2.5.5 From preliminary data received from vendors it appears we will require a pumping system capable of furnishing cleaning solutions to the heads at 100 psig and 130 GPM per head.

2.2.5.6 Consideration should be given to reducing the flow rate of the cleaning solutions as much as possible, since recycling of the flow streams may not be possible due to biological contamination. If all liquids used for flushing and cleaning must be treated and disposed of, this could be a major consideration.

2.2.5.7 Due to cleaning considerations, and possible problems in being able to flush the flat sloping bottom of the tanks configured on the data sheets, two other tank shapes are presented for consideration in Appendix A-6. The initial cost of the alternate shapes shown would be greater, but the difference in initial cost might be compensated for by shorter cleaning cycles and less cleaning waste to have to treat and dispose of. An actual installation, operating, and cleaning cost analysis would have to be performed to get a true cost comparison.

2.2.5.8 Because of the number of tanks that would be involved in this facility, it is recommended that either:

1. A test program be arranged with a cleaning head vendor(s) to assure a sloped flat bottom tank could be effectively flushed clean, and to determine minimum flow rates that could be used to achieve the degree of cleanliness required, or

2. Existing tanks in the size range being considered for this plant, with existing cleaning systems in place be located and the effectiveness of existing cleaning cycles and systems be reviewed.

2.2.6 Identify in the Final Report the Associated Subsystems or Common Design Considerations not Included in the Report.

2.2.6.1 Tank Internals

It is assumed for purposes of this study that the tanks contain no internal baffles, mixers, coolers, or piping that will complicate the layout and location of cleaning heads, and change the requirements of the number and types of heads required.

2.2.6.2 Cleaning Solution(s) Mixing, Storage, Delivery, and Removal, Separation, and Treatment Systems.

None of the above are considered in this study. Cleaning solution storage, mixing, and pumping facilities might be required to be quite extensive depending on the number of tanks being cleaned and the length, number of cleaning cycles, and liquid flow rates. Removal of cleaning solutions might require slightly elevated tank foundations, tanks, or extensive drain sump systems. A filter system will be required to remove solids, and systems for solids treatment, liquids treatment, or re-cycle might be required.

2.2.6.3 Separate nozzles for cleaning inside manways and large diameter nozzles are not considered.

2.2.6.4 Cleaning solutions delivery systems to the tanks are not considered. Piping to deliver the cleaning solutions to the cleaning heads, to the point of connection outside the tank could be expensive and might require special alloys or materials consideration depending on the cleaning solution(s) chemistry.

2.2.7 Estimate Total Installed Costs Using Standard Estimating Practices. Prepare Purchased Equipment and Total Installed Cost Curves.

The highest quoted cost of a single cleaning machine for any tank in the size range considered is $3,700.00. Installation of a single cleaning machine would require a 2" stainless steel pipe mounting lance be welded thru a 10" Dia. blind flange.

Purchased Equipment Costs are estimated to be:

Cleaning machine (incl. shipping and handling)	$4,200.00
Mounting adapter and lance	$2,500.00
TOTAL	$6,700.00

Total installed costs are estimated to be $10,000 for each machine.